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PERFORMANCE EVALUATION OF ROUNDABOUTS USING A MICROSCOPIC SIMULATION MODEL

Summary. Contemporary planning of the road network in cities assumes the use of transport models. The microscopic model allows provision of information and decision-making regarding, for example, emissions, traffic organisation, geometrics of the intersection and traffic control system. This article describes the development of comprehensive methodology applied for carrying out the research related to the design of geometrical parameters of the roundabout. The methodology involves developing instructions for preparing solutions for performance evaluations of roundabouts using a microscopic simulation model with the VISSIM software. The application of the developed methodology was prepared on the case study of the roundabout in Gdańsk. The results of the prepared case study were discussed.

Keywords: microscopic traffic simulation model, traffic parameters, project of intersection geometry.

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1. INTRODUCTION

An intensive process of development of the new intelligent transportation systems (ITS) was observed. ITS connects many types of services and technologies with the goal of improving the effectiveness of transport systems [1,2,3,4]. Contemporary planning of the road network in cities assumes the use of transport models. Three types of transport model can be distinguished [5]:

- macroscopic model – highest level of aggregation, lowest level of detail
- mesoscopic model – high level of aggregation, low level of detail
- microscopic model – low level of aggregation, highest level of detail

In this article, the authors examined the microscopic model, which describes the impact between individual vehicles in traffic [6]. The microscopic model allows provision of information and decision making regarding: emissions, traffic organisation, geometrics of the intersection, traffic control system and others [7]. Many simulation tools exist for developing traffic microscopic simulation models, for example, VISSIM, SimTraffic, AIMSUN, CUBE Dynasim, SUMO and others [8]. In this study, the VISSIM software was used for the case study problem investigated.

The microscopic simulation traffic model is a useful tool for analysis of the impact of planning new infrastructure. The author in [9] analysed the estimation of effects caused by the implementation of the Park&Ride system into a transport hub with the CUBE Dynasim model.

A simulation software was used to test a special type of traffic control. The dynamic management of traffic lights at pedestrian crossings with fuzzy logic controllers was tested with an external interface module in the VISSIM software for extensive simulative assessments [10].

Air quality is an extremely important factor in urban centres. The authors in [11] used a life cycle assessment model and prepared a microscopic simulation model with the VISSIM software for a comparative study of emissions by road maintenance works.

This article has two main aims. First, the authors described the development of methodology applied for carrying out the research related to the design of geometrical parameters of the roundabout. The methodology involves developing instructions for preparing solutions for performance evaluations of roundabouts using a microscopic simulation model with the VISSIM software. The second aim of the paper was connected with the application of the methodology to the case study of a roundabout in Gdańsk.

The article is organised as follows; section 2 provides information about the research problem and a description of the case study. The next section presents the development of the methodology applied to carry out the defined research problem. Section 4 contains the results of using a microscopic simulation model prepared through the developed methodology for the case study. Section 5 of the paper contains conclusions and propositions for future work.

2. CHARACTERISTICS OF THE RESEARCH PROBLEM

The research problem is related to the proposition for geometrical changes in the roundabout at Gdańsk. The changes are associated with intensive cargo traffic from the road inlet from the port of Gdańsk. Prognostic analysis of road traffic indicates an increase in traffic flow in subsequent years in the analysed inlet. The aim of solving the problem is to compare traffic conditions depending on values of the traffic flow in the proposed variants of the design of the roundabout inlet for all prognostic years. The cargo traffic flow growth related to the development in the port was calculated in all prognostic years.

The need to carry out the analysis of such a problem in the above-mentioned scope is related to the transport service of the port in Gdańsk. Figure 1 presents the existing state of the analysed roundabout in Gdansk with the inlets descriptions. Solving the problem requires the development and validation of the following variants:

- the existing state (mapping the process of handling traffic by crossing in the current traffic situation) and in all traffic flow prognostic years
- proposals to change the geometry of the intersection on one of its inlets (E2) in all traffic flow prognostic years (variant 1)
- proposals to change the geometry of an intersection on one of it's inlets (E2), while eliminating traffic on one of the relations that uses this intake (relation from inlet E2 to outlet S), because instead of a roundabout, this relation will be served by an overpass (variant 2) in all traffic flow prognostic years

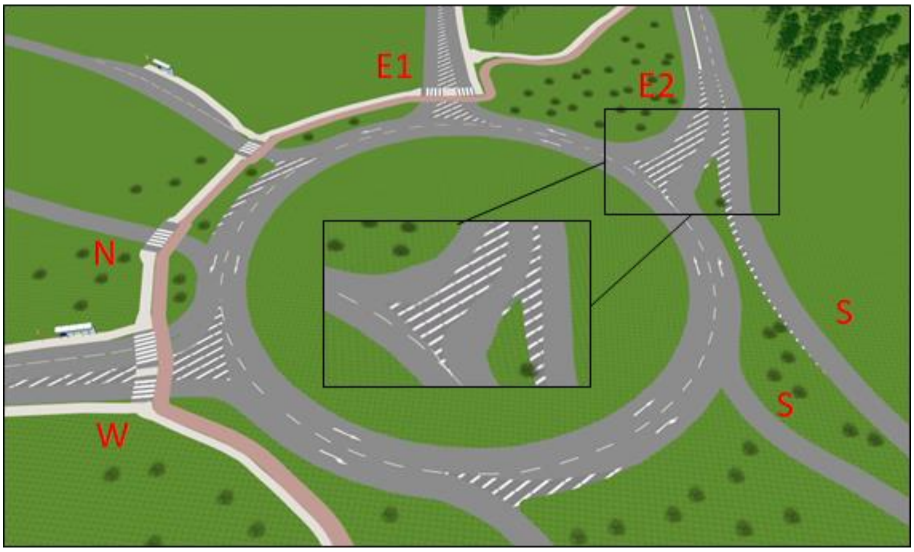

Fig. 1. Existing state of the analysed roundabout in Gdansk
Source: author's own collaboration

The variant 1 of the changes of the geometry is presented in Fig. 2. In the inlet E2 proposed the addition of a new road lane.

Figures 1 and 2 showed microscopic simulation models prepared in the PTV VISSIM software. The roundabout studied was in the area of the "Ku Ujściu" traffic node in Gdańsk. The roundabout is an intersection of Ku Ujściu Street with national road number 89 with additional interchanges with Majora Sucharskiego Street. Developed methodology in this article shows the way to solve such a problem.

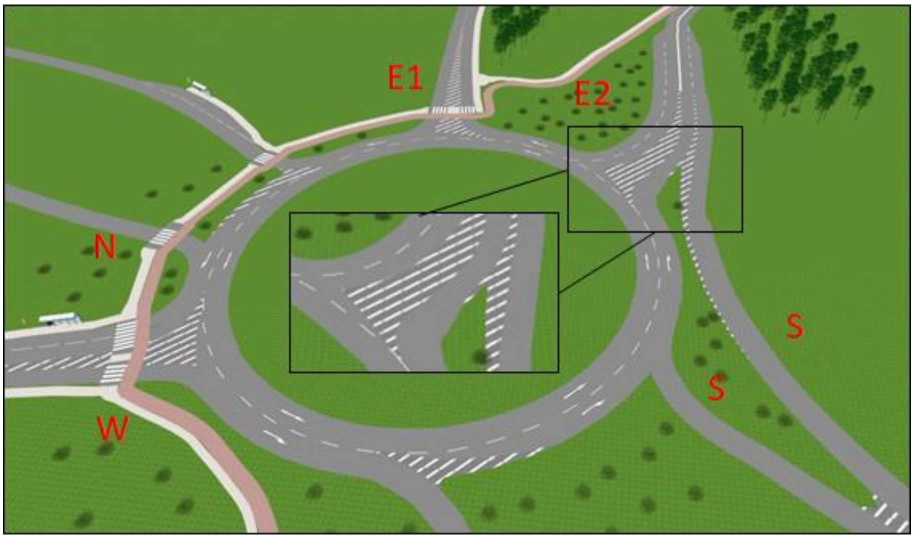

Fig. 2. Proposal to change the geometry of an intersection on inlet E2 with the addition of a new road lane
Source: author's own collaboration

3. METHODOLOGY OF THE RESEARCH PROBLEM

A comprehensive methodology for solving the indicated research problem was developed. The developed methodology allows for the assessment and provision of solution for performance evaluations of roundabouts using a microscopic simulation model with the VISSIM software. The selected traffic simulation software was developed by the PTV Group in Germany [12]. The VISSIM software is a comprehensive tool used in developing the microscopic simulation model, which also has the capability of rendering a 3D visualization [13].

The methodology described can be used to solve other research problems other than the described case study in the article. The implementation of the research based on the developed methodology attends to all the relevant aspects related to the development of the microscopic traffic simulation model. The developed method was divided into four stages:

- defining and characterising the research problem
- development and analysis of the research and measurements
- microscopic simulation model development
- analysis and evaluation of the simulation results

Each stage is connected with the other. Solving the research problem with prepared methodology requires the usage of all stages. All of the stages were described using schemes as presented in Figures 3 to 6.

The first step of the methodology deals with defining and characterising the research problem. Figure 3 shows the scheme of the first step of the methodology. The five main categories related to the scope of the research problem were identified. The scheme considers all the important factors for solving the research problem. Defining the factors presented in Fig. 3 is extremely important because it directly influences the subsequent stages of the methodology. The methodology in that step showed the necessary measurements to be done.

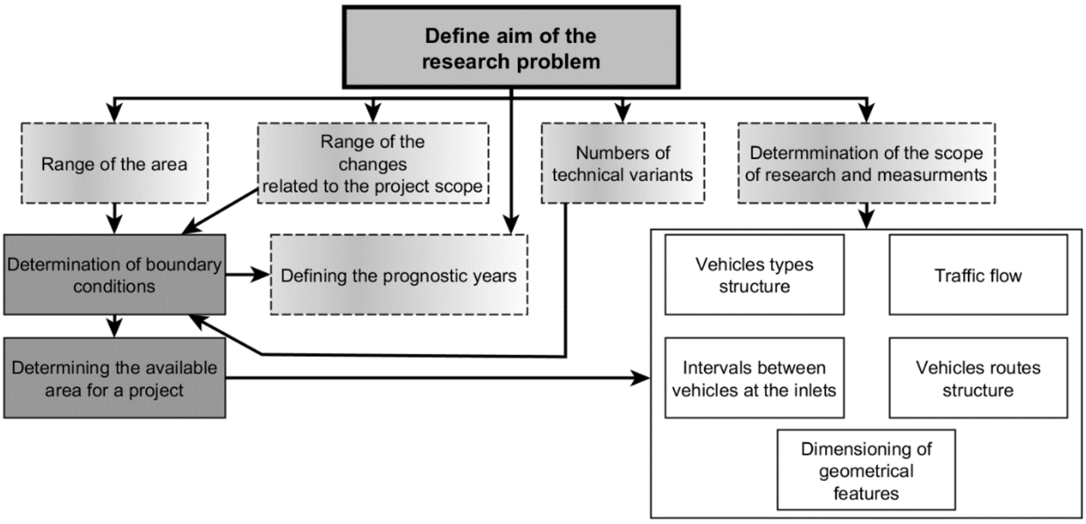

Fig. 3. Scheme of first step of the methodology: defining and characterising the research problem
Source: author's own collaboration

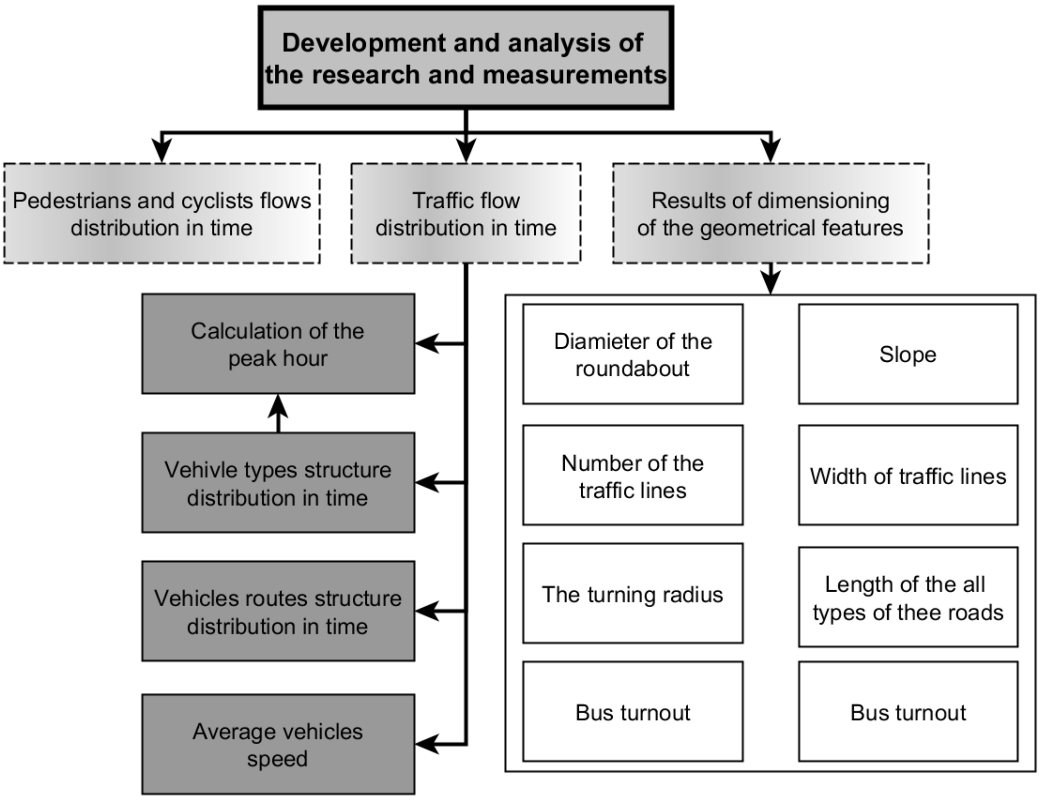

Fig. 4. Scheme ofe second step of the methodology: development and analysis of the research and measurements
Source: author's own collaboration

Figure 4 shows the scheme of the second step of the methodology: development and analysis of the research and measurements. The second step describes the necessary analysis of the obtained data from the first step. The traffic and geometric data analyses are necessary to build a microscopic traffic model. The geometrical measurements are often conducted using geo-information software or with devices for non-contact measurement of geometric values. The traffic data were collected using different approaches, for example, video detection, manual counting. Performed analyses of the acquired traffic data require the use of standards described in the literature depending on the country, for example, HCM [14], HBS [15], Poland [16].

The methodology of the microscopic simulation model development was presented in Fig. 5. The diagram includes all components related to the development of the roundabout microscopic simulation model. The development of the model is possible only after the implementation of the previous steps. The development of the model is related to the geometrical structure of the intersection represented by, for example, the VISSIM software components, such as links, nodes, connectors, vehicle routes. The components are parametrised and define using analysed traffic data from the previous step.

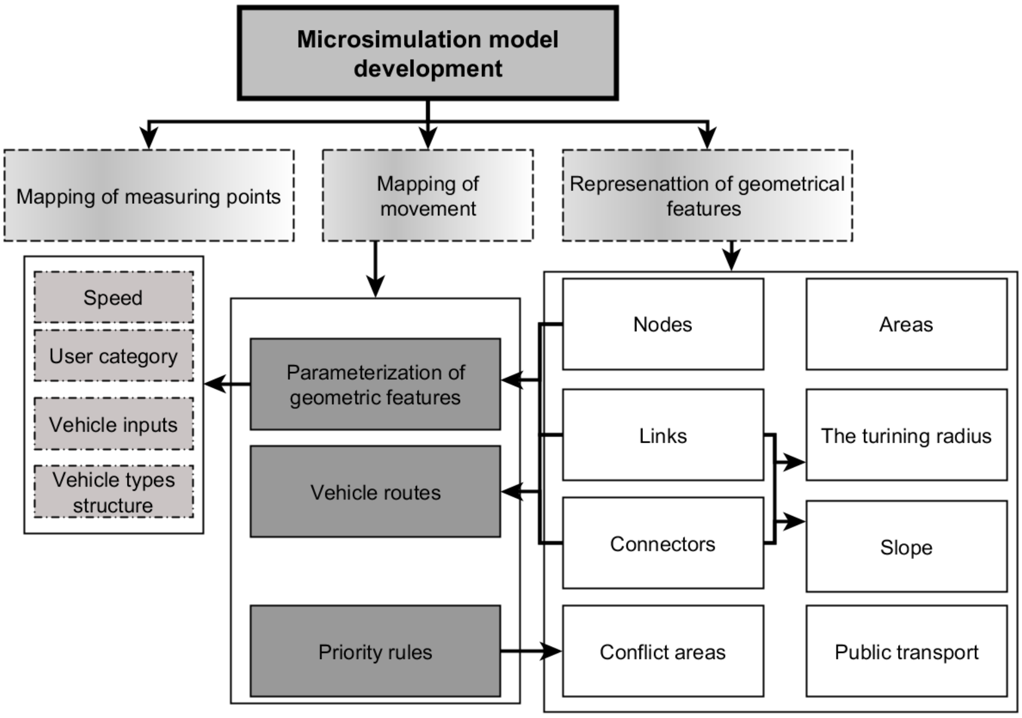

Fig. 5. Scheme of third step of the methodology: microscopic simulation model development.
Source: author’s own collaboration

Analysis and evaluation of the simulation results scheme were presented in Fig. 6. The scheme was presented using a block diagram. The basis of the evaluation algorithm is to define the evaluation criteria and the selection of assessment measures. Defined in detail, the criteria grants understanding of the results in different technical variants and analyses the changes in the prognostic years. In order to check the correctness of the developed microscopic simulation model of the existing state, validation was performed. Calibration was performed, for example, by comparing the obtained values of an average wait time or travel time from the model and measured by video techniques [17]. Only the calibrated microscopic simulation model can be used to obtain and compare results in the technical variants and analyses the changes in the prognostic years.

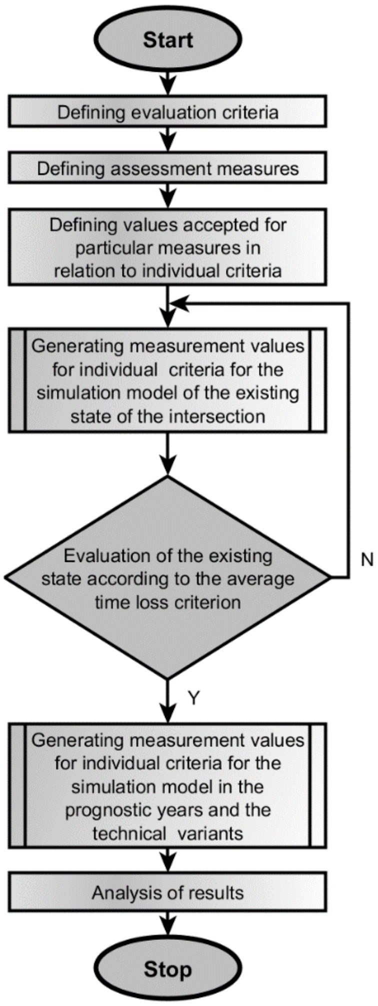

Fig. 6. Scheme of fourth step of the methodology: analysis and evaluation of the simulation results.
Source: author's own collaboration

Presented in a comprehensive manner, the methodology shows the preparation of the complex microscopic simulation model. The developed methodology for solving the indicated research problem was used for the case study presented in section 2.

4. CASE STUDY RESULTS

The microscopic traffic simulation models were developed using data from road traffic measurements. Based on the obtained traffic flow data, the percentage shares of peak hours - morning and afternoon in the daily traffic flow, as shown in Tab. 1 were determined.

For further analysis, the morning peak hour was chosen, because the intensity of traffic in this period is greater, which enables mapping of the worst traffic conditions.

Data from traffic prognostic years including daily traffic volume were calculated for hourly traffic based on traffic percentage share from the morning peak hour in the daily traffic (8.06%). For each prognostic years horizon, traffic intensity and percentage shares of the routes and vehicle types structure for all relations at the round-about were determined.

Tab. 1

Percentage share of traffic from peak hours in daily traffic

Peak hours	**Time of the peak hour**	**Traffic flow [veh./h]**	**Percentage share of traffic flow from peak hour in daily traffic [%]**
Morning	06:00 - 07:00	892	8,06
Afternoon	15:00 - 16:00	838	7,57

Source: author's own collaboration

All elements in the microscopic simulation model were placed according to the method of developing models using the PTV VISSIM software.

On the basis of average loss of time at the roundabout and individual at the inlets for particular horizon in prognostic years, levels of service were determined on the basis of the "Method for calculating capacity of the roundabouts" published by the General Directorate of National Roads and Highways in 2004 [18]. This is the current valid method of assessing traffic conditions at roundabouts in Poland.

Table 2 presents the criteria for defining levels of service based on average values of time losses d [s / P] according to the current method in Poland.

Tab. 2

Levels of service for a given average values of time losses

Level of service (LOS)	**Assessment of traffic conditions**	**Average values of time losses *d* [s/veh.]**
I	Very good	<15,0
II	Good	15,1 - 30
III	Average	30,1 - 50
IV	Bad	>50

Source: author's own collaboration

Table 3 presents the average values of time losses d [s/veh.] for the roundabout along with the levels of service indication for existing state model and models in two variants. These values were compiled in all prognostic years.

The results presented in Tab. 3 indicate that the roundabout will reach IV level of service in 2034, for the current state and for the first variant. The results of the simulation indicate that the addition of a second lane (variant 1) at the inlet E2 will reduce the average values of time losses at the intersection. For 2030, the level of service of the roundabout from level III to II was improved. In the prognostic horizon for 2040, the average values of time losses in variant 1 were observed rather than in a situation where the facility would not be reconstructed. For the year 2050, the average values of time losses from the model taking into account the change of the inlet geometry E2 are greater than for the existing state.

Tab. 3

Levels of service for a given average values of time losses

Technical variants	**Prognostic years**	**Average values of time losses *d* [s/veh.]**	**Level of service (LOS)**
The existing state	2018	5,23	I
	2030	30,19	III
	2034	108,69	IV
	2035	110,43	IV
	2040	154,27	IV
	2050	155,26	IV
Variant 1 - proposals to change the geometry of the intersection on one of it's inlets (E2)	2018	4,70	I
	2030	18,24	II
	2034	89,36	IV
	2035	101,54	IV
	2040	143,29	IV
	2050	175,22	IV
Variant 2 - proposals to change the geometry of an intersection on one of it's inlets (E2), while eliminating traffic on one of the relations that uses this intake (relation from inlet E2 to outlet S)	2018	3,58	I
	2030	5,29	I
	2034	6,87	I
	2035	6,89	I
	2040	8,39	I
	2050	11,85	I

Source: author's own collaboration

It is related to the methodology of determining average values of time losses by the VISSIM software. For the existing state, the program did not generate traffic flow, which was set by users. This resulted from the limitation of the E2 inlet capacity and the formulating queues of vehicles that were not served at the simulation time.

The elimination of E2 - S relation at the roundabout in the second variant caused a radical improvement of traffic conditions. Undoubtedly, this direction should be explored in further analysis and design work. However, this solution involves incurring significant financial outlays.

5. CONCLUSIONS

The developed methodology adequately tackled the research problem presented in the article and may be applied to similar research problems. The development of the model using the VISSIM software, due to its wide possibilities, effectively determine the impact of changes made to the roundabout on traffic conditions.

The following conclusions were distinguished for the analysed case:

- Changing the geometry of the E2 inlet at the roundabout has a positive effect on the traffic conditions at this inlet because in individual prognostic horizons average values of time losses are less by about 40 [s/veh.]. However, this does not solve all communication problems occurring at this intersection, because in 2034, this facility will be working on IV level of service. This was observed in both the analysis of the existing state model and the models taking into account the change of the inlet geometry E2.
- The improvement of traffic conditions after the addition of the lane at the E2 inlet will increase the average values of time losses for relations on other inlets. This phenomenon was caused by the increase in the traffic volume on the roundabout envelope, which reduces the average time interval between vehicles. The increase in traffic is the result of both the prognostic change in traffic potentials in the immediate vicinity of the intersection as well as the general pattern of socio-economic changes manifesting, inter alia, an increase in the motorisation index and an increase in the population's mobility.
- Elimination of E2 - S relation at the roundabout resulted in a radical improvement of traffic conditions. Undoubtedly, this direction has potentials for future analytical and design work.

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